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Publication date:
2014

Citation (APA):
Hejlesen, M. M., & Walther, J. H. (2014). *Simulations of a single turbulent vortex ring using a regularized particle-mesh based vortex method*. Poster session presented at 11th World Congress on Computational Mechanics, 5th European Conference on Computational Mechanics, 6th European Conference on Computational Fluid Dynamics, Barcelona, Spain.

11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20–25, 2014, Barcelona, Spain

SIMULATIONS OF A SINGLE TURBULENT VORTEX RING USING A REGULARIZED PARTICLE-MESH BASED VORTEX METHOD

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Key words: *Vortex rings, turbulence, particle-mesh methods, regularized vortex methods.*

Vortex rings has been subject to intense experimental and numerical research [1, 2, 3] in order to gain valuable insights into the evolution and instability of vortex structures. Studying the flow topology of this fundamental flow structure has extended the knowledge about the dynamical instability and the eventual transition to turbulence of rotating flow structures such as vortex rings.

Recent numerical simulations by Bergdorf et al. [2] and Archer et al. [3] have presented a detailed analysis of the modal instabilities of vortex rings and the presence of secondary vortex structures surrounding the vortex ring core. The numerical simulations [2, 3] were performed at Reynolds numbers of 5.500, 7.500 and 10.000 and was in all cases performed using periodic boundary conditions. Here we refer to the vorticity formulated Reynolds number $\mathrm{Re}_\Gamma = \Gamma/\nu$ where Γ is the circulation of the vortex ring cross section and ν is the kinematic viscosity.

In the present work we use an unbounded vortex method to perform direct numerical simulations of vortex rings with Reynolds numbers of 5.500, 10.000 and 20.000. The method uses a recently developed unbounded Poisson solver [4], which is based on regularized Greens functions to obtain high order convergence. Thus by simulating the vortex ring with unbounded conditions we are able to minimize the size of the computational domain and avoid the effect of periodicity and perform simulations at a higher Reynolds number than previously presented.

The high order Poisson solver has been implemented in an unbounded particle-mesh based vortex method which uses a re-meshing of the vortex particles to ensure the convergence of the method. Furthermore, a re-projection of the vorticity field is performed at each time step to ensure a divergence free vorticity field. This re-projection has shown to have

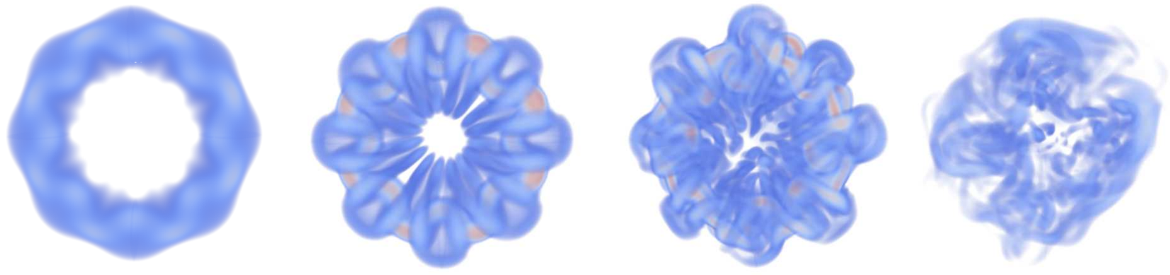

Figure 1: The contour of the magnitude of the vorticity of four different stages of the vortex ring of $\mathrm{Re}_\Gamma = 10.000$. The figures (a) and (b) clearly show an azimuthal instability which causes the formation of secondary vortex structures forming around the vortex core. At later stages (c) and (d) the vortex structures transitions to a more chaotic state which eventually dies out due to viscous diffusion.

a significant effect on the dynamic behavior of the vortex ring.

As mentioned earlier, the resulting vortex method is based on the regularized vorticity and velocity field and it is shown that using these higher order methods is equivalent to using an explicitly filtered large eddy simulation with an approximate deconvolution model. Hence the obtained method is inherently similar to the approximate deconvolution model proposed by Stolz et al. [5]. In Figure 1 we show four different stages of the vortex ring as it develops over time. The instability and break-down behavior are observed to be in good agreement with previous numerical simulations of Archer et al. [3].

REFERENCES

[1] T. Maxworthy. Some experimental studies of vortex rings. *J. Fluid Mech.*, Vol. **81**, 465–495, 1977.

[2] M. Bergdorf, P. Koumoutsakos and A. Leonard. Direct numerical simulations of vortex rings at $Re_\Gamma = 7500$. *J. Fluid Mech.*, Vol. **581**, 495–505, 2007.

[3] P. J. Archer, T. G. Thomas and G. N. Coleman. Direct numerical simulation of vortex ring evolution from the laminar to the early turbulent regime. *J. Fluid Mech.*, Vol. **598**, 201–226, 2008.

[4] M. M. Hejlesen, J. T. Rasmussen, P. Chatelain and J. H. Walther. A high order solver for the unbounded Poisson equation. *J. Comp. Phys.*, Vol. **252**, 458–467, 2013.

[5] S. Stolz, N. A. Adams and L. Kleiser. An approximate deconvolution model for large-eddy simulation with application to incompressible wall bounded flows. *Phys. Fluids*, Vol. **13**, 997–1015, 2001.